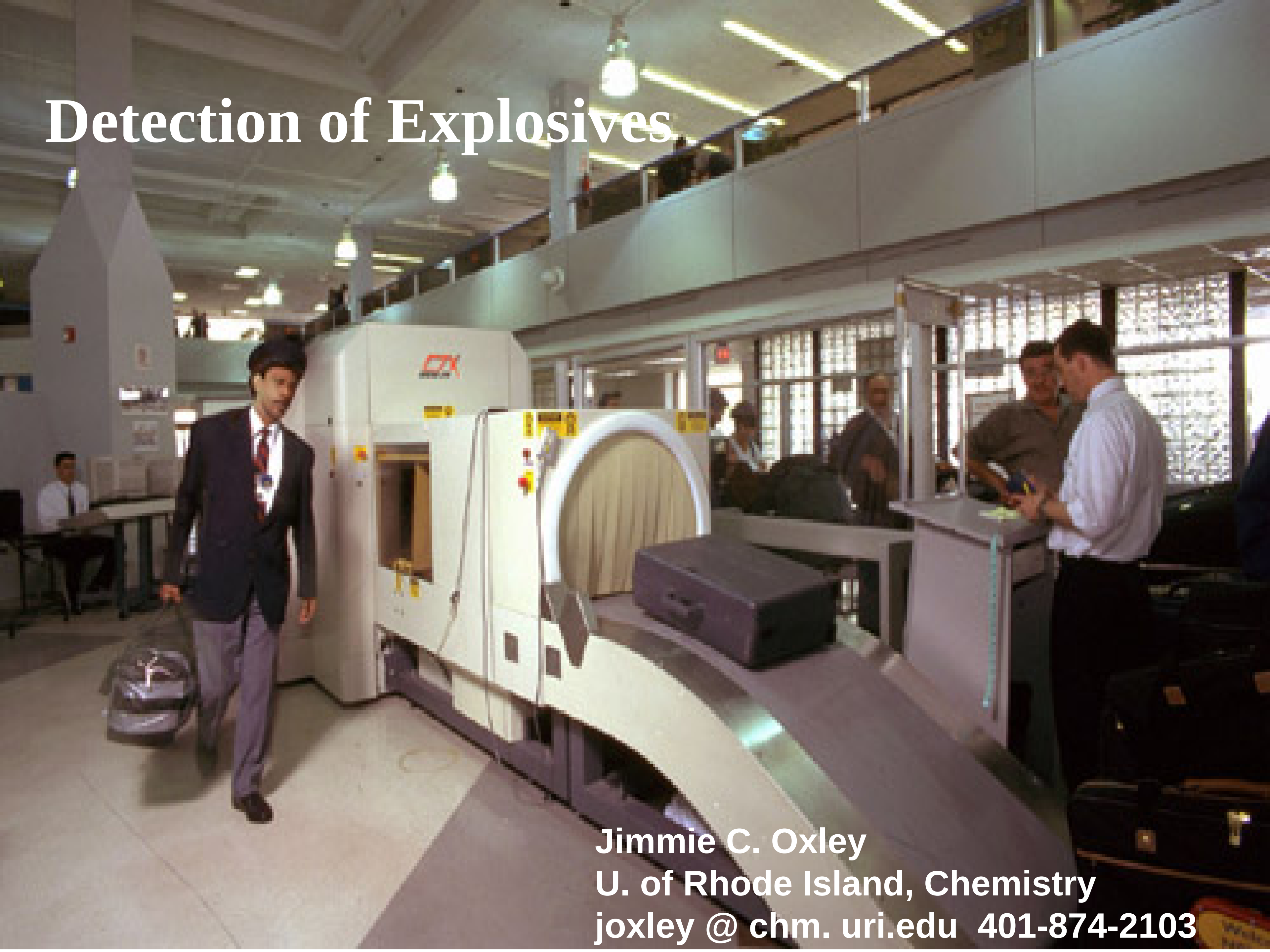
Detection of Explosives



Jimmie C. Oxley
U. of Rhode Island, Chemistry
joxley @ chm. uri.edu 401-874-2103

What the Public will Tolerate

Threat Vectors

Trace Detection Techniques

Electron Capture Detection (ECD),
Ion Mobility Spectrometry,
Chemiluminescence,
Mass Spectrometry,
Polymers,
IR & Raman Spectroscopy
Immunoassay,
Cantilever beam detectors,
MEMS (micro-electro-mechanical system)
Dogs,
Rats & Bees.

Trace Detection Techniques

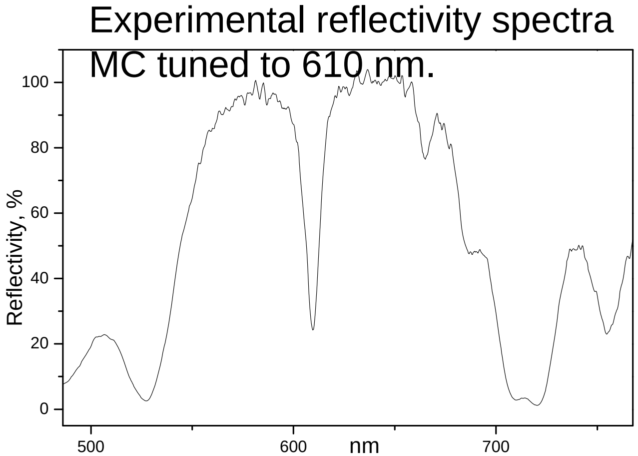
Trace matches chemical property to a library. Result should be lower false alarms than bulk.

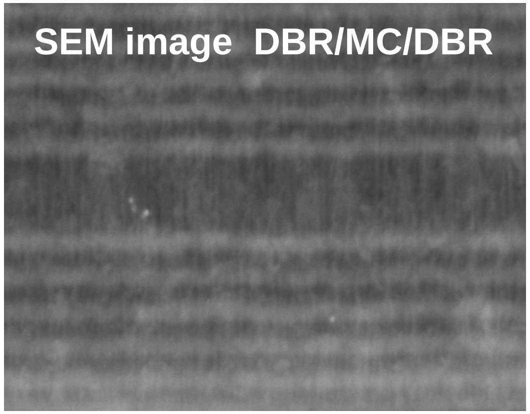
Nuisance alarms & malicious contamination are possible. No spatial or quantitative information to aid alarm resolution.

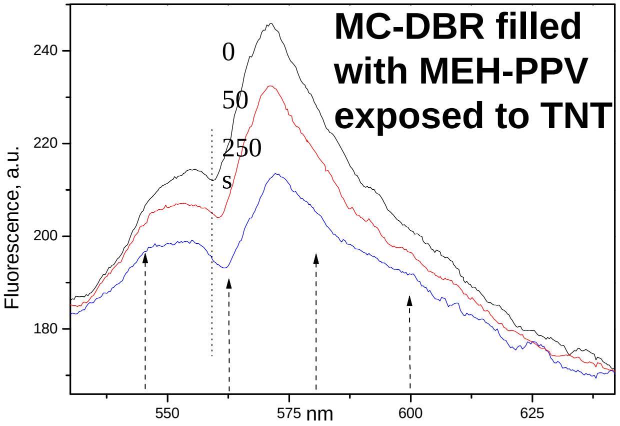
Efficient collection of vapor or particulate & getting it to the detector is a problem.

Polymers for Explosive Detection

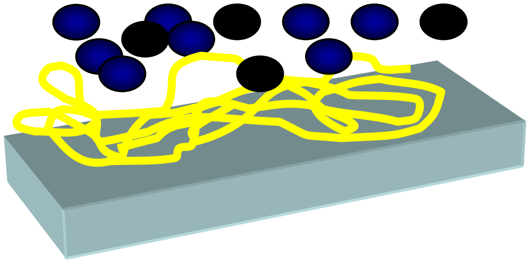
Fluorescence generation, quenching and lifetime quenching are used to detect the presence of explosive and explosive like groups amino- or nitro-

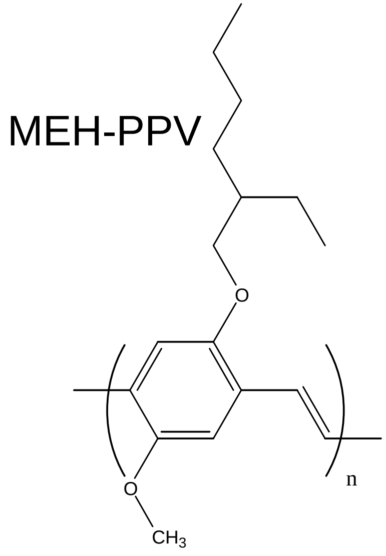






To add selectivity, an orthogonal detection scheme is suggested. Distributed Bragg Reflector (DBR) contains 10 period porous silicon multilayers with 36% and 59% porosities. The 210 nm thick micro-cavities (MC) between two DBRs has 36% porosity.



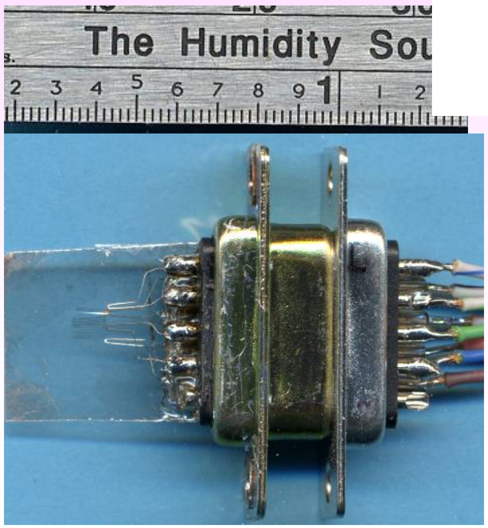


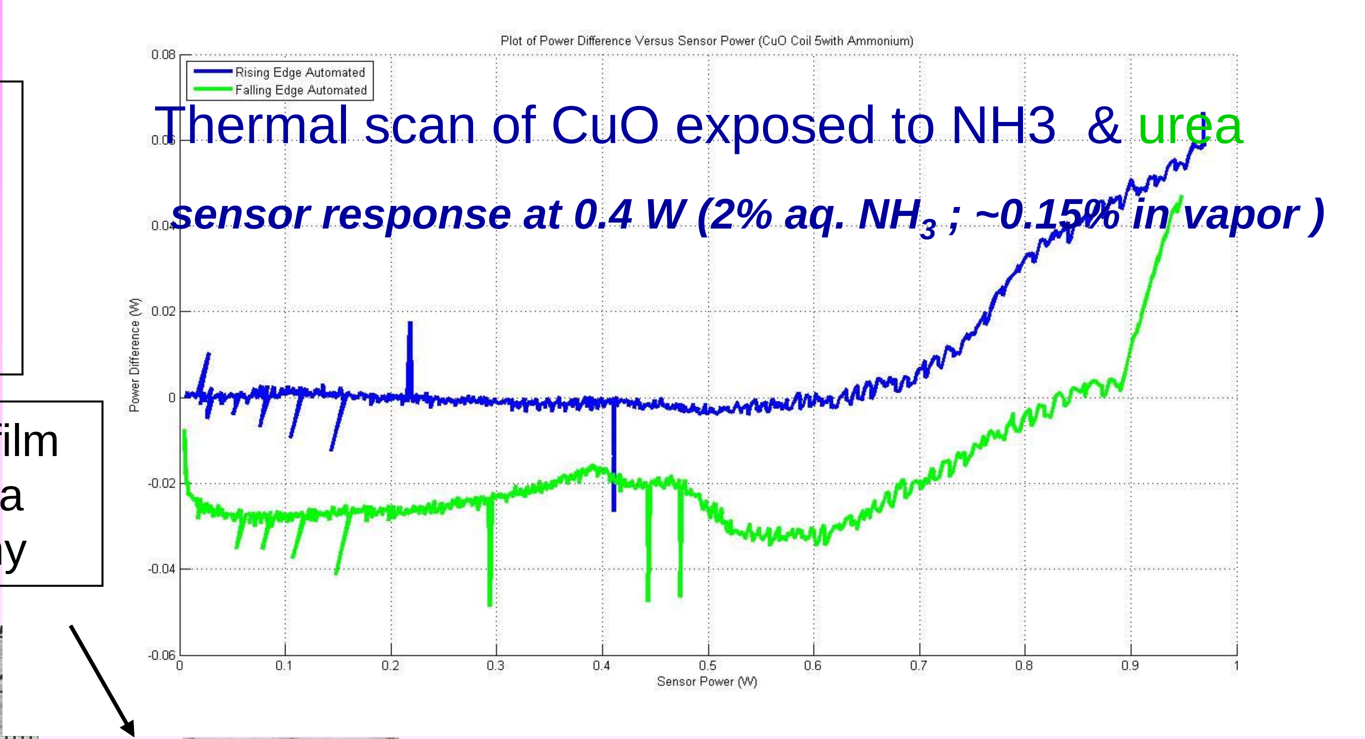
Detection of Specific Gases by Metal Oxide Catalysis

These simple, cheap gas sensors from specific 3D metal oxides will detect minute concentrations of specific gas molecules***--explosives & precursors***

wire-wound (12 um dia. Ni coil) microheater gas sensor with DB9 connector

fabricated thin film microheaters via photolithography

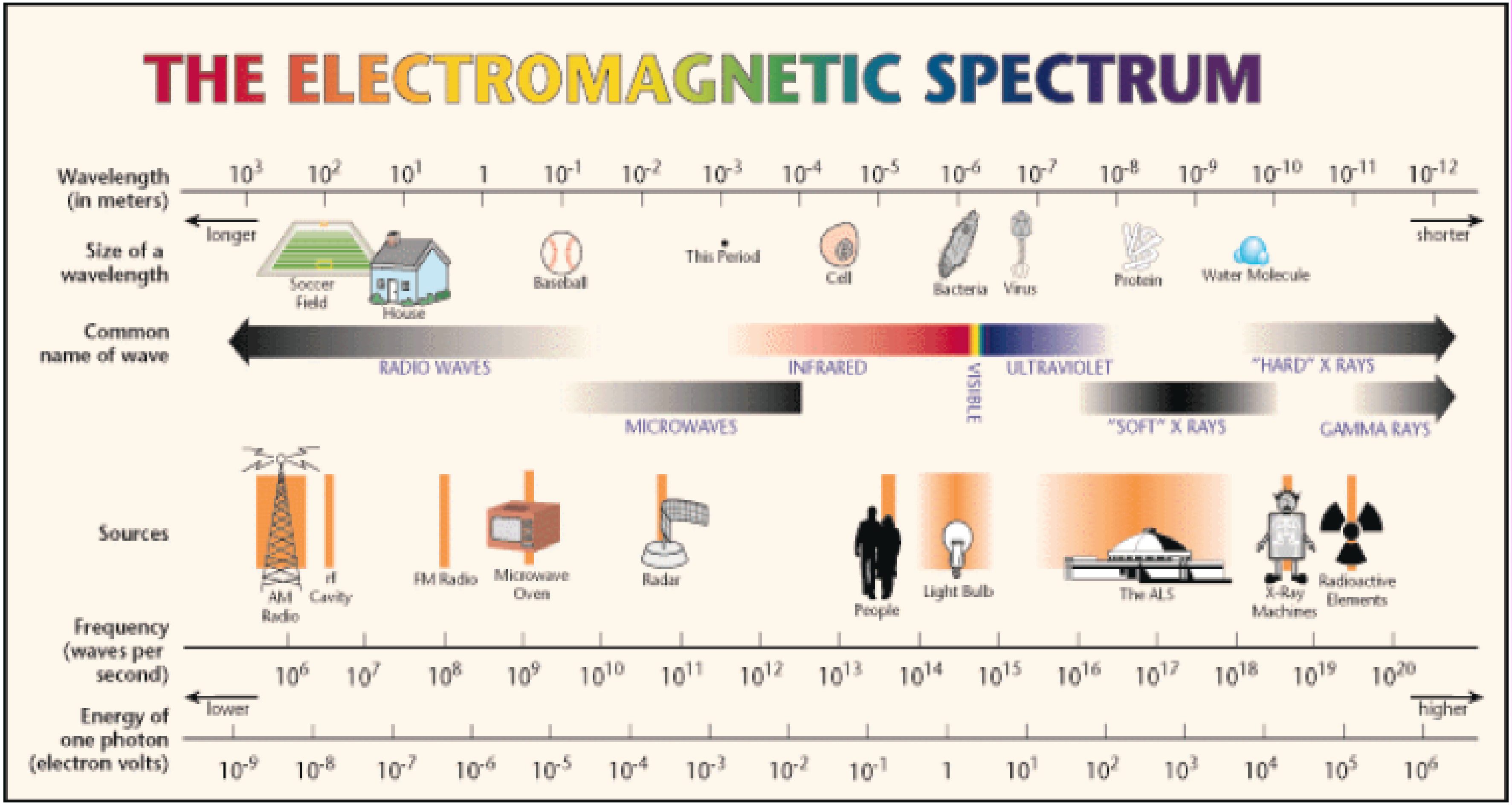


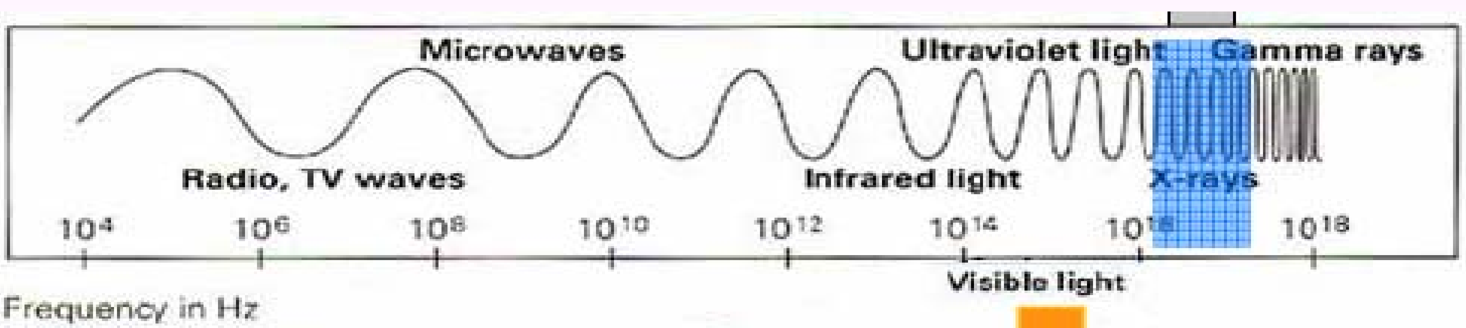


For early immediate detection of toxic gases in building ventilation systems & other enclosed areas, eg stadiums, airports, subways, train stations.

No interference from background gases

Sweeping HVAC for suspected “bomb” lab


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
lower
higher
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6


Microwaves
Ultraviolet light
Gamma rays
Radio, TV waves
Infrared light
X-rays
10^4 10^6 10^8 10^10 10^12 10^14 10^18
Visible light
Frequency in Hz

Bulk Detection Techniques

Bulk detection uses characteristic emission or attenuated signal from sample to identify threat material.

Emission usually elicited by bombarding sample with particles or rays.
Exception: passive millimeter wave detection distinguishes unique thermal energy of human flesh.

Emission results from specific properties of class of explosive or drug.
Exception: coherent x-ray diffraction & NQR require libraries.

High density & high nitrogen and oxygen content are characteristics, but not unique to explosives.
False alarms tend to be higher than with trace.
Bulk detection gathers spatial & quantitative information.

Detection schemes capitalized on unique explosive properties.

X-ray Techniques

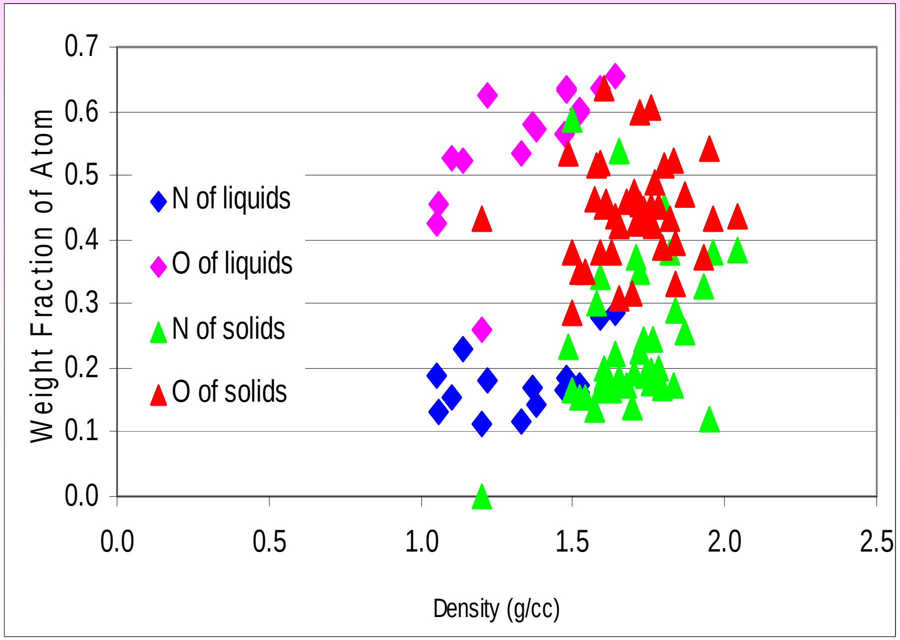
--Standard Transmission, CT, Dual-Energy, Backscatter, Low-dose, Coherent, K-edge, High-Energy

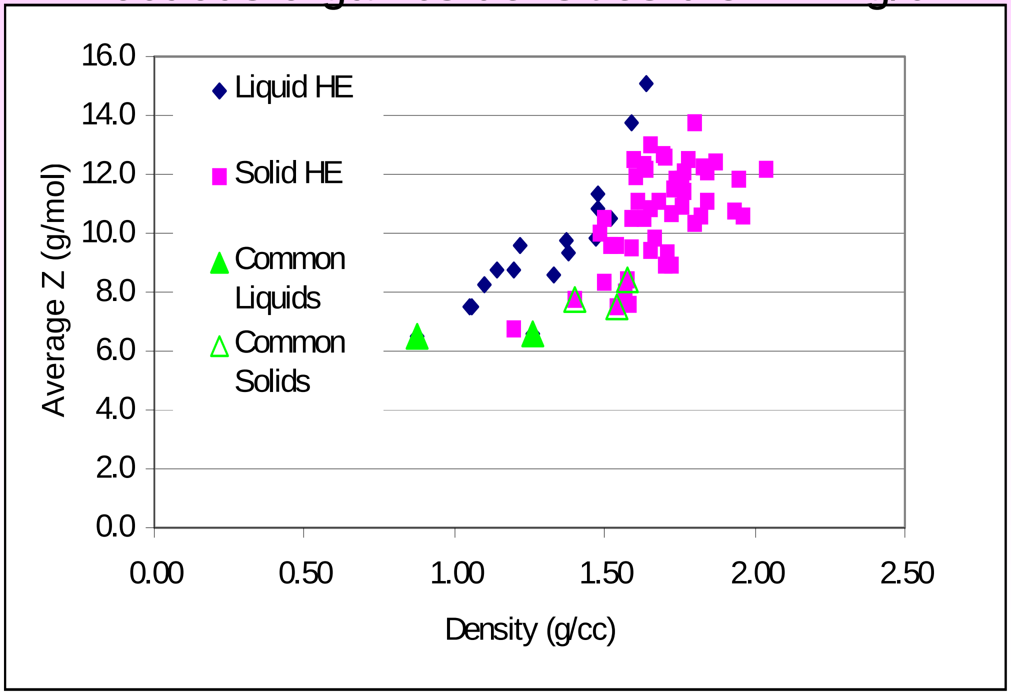
Nuclear Detection Techniques

--TNA, FNA, PFNA,GRA, NRA, FNAS, FNTS, API, PhotoNuclear Activation, PhotoFission

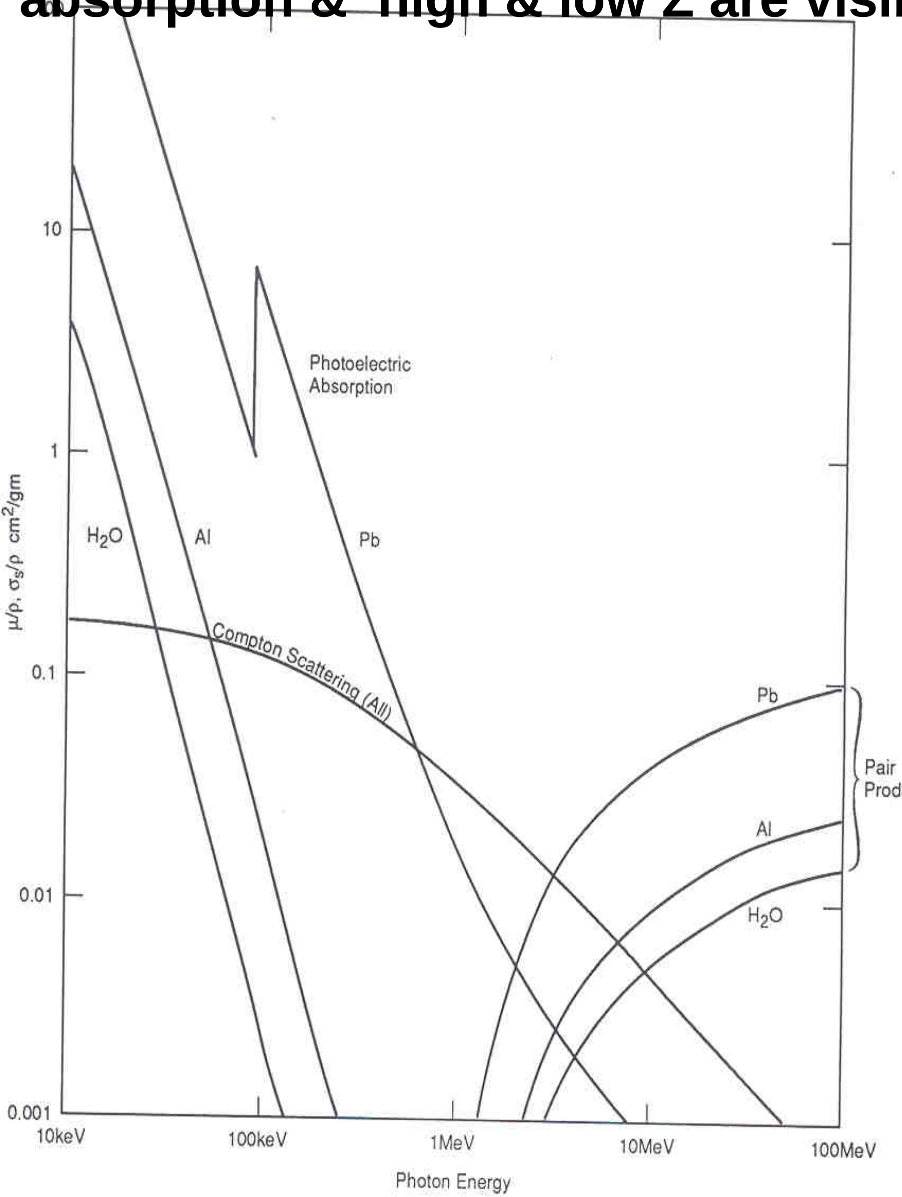
Explosives are rich in N or O or both.

Typical explosive densities 1.5 to 1.8 g/cm^3, innocuous organics densities 0.8 - 1.2 g/cm^3.

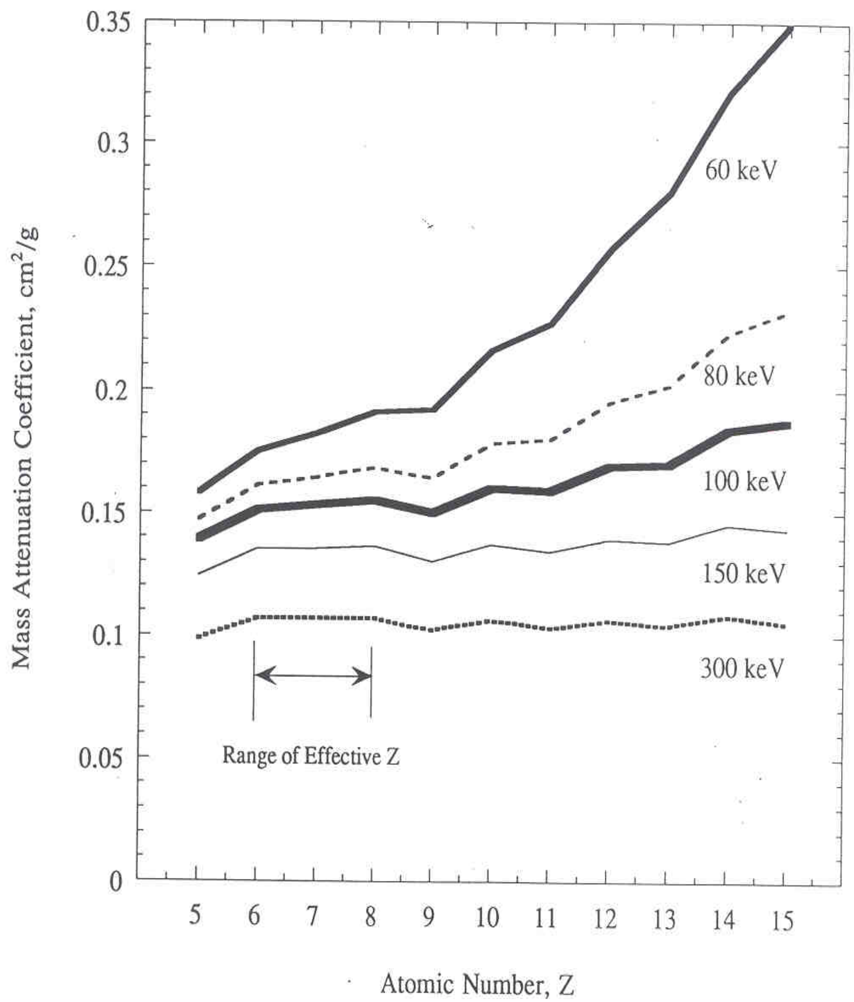




Low energy (50-75 keV) X-ray device looks at beam absorption. It is most sensitive to high Z_{eff} materials. As x-ray energy increases, Compton scattering, which is insensitive to Z_{eff}, becomes more important than absorption & high & low Z are visible.



Absorption Coefficient, μ, versus Atomic Number For X-Ray Energies from 60 keV to 300 keV



Bulk Detection: X-ray

X-ray gives 2D spatial resolution better than nuclear techniques. X-ray cone can be focused into a beam using a “flying spot” collimator. Resolution to millimeters can be achieved.

X-ray can be standard, radiographic, tomographic, dual energy, or backscatter.

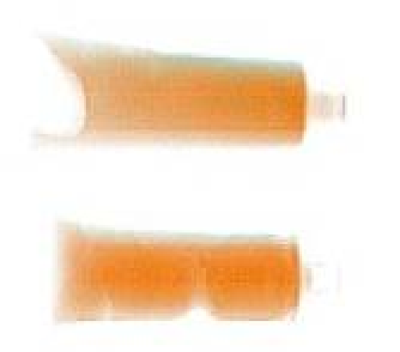
Low energy x-rays are not very penetrating; thus, they do not work well for cargo inspection.

Nuclear techniques have penetration power because they use neutrons or gamma rays). They can discriminate chemical elements, but they are high cost, large, most require shielding & an accelerator, and resolution significantly worse than x-ray.

Neutron beam is often collimated (wastes beam). Target material is required to make a mono-energetic beam.

Detectors and discrimination algorithms to compensate for cluttered background are technical challenges.

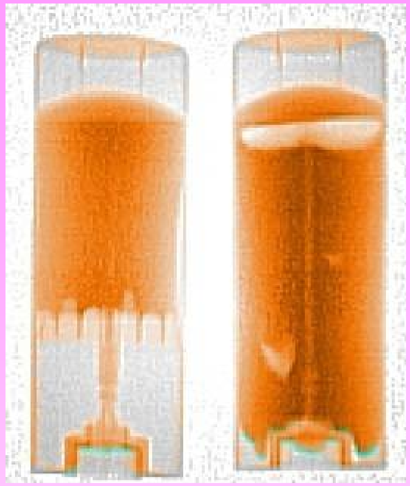
Imaging of Explosives



Toothpaste

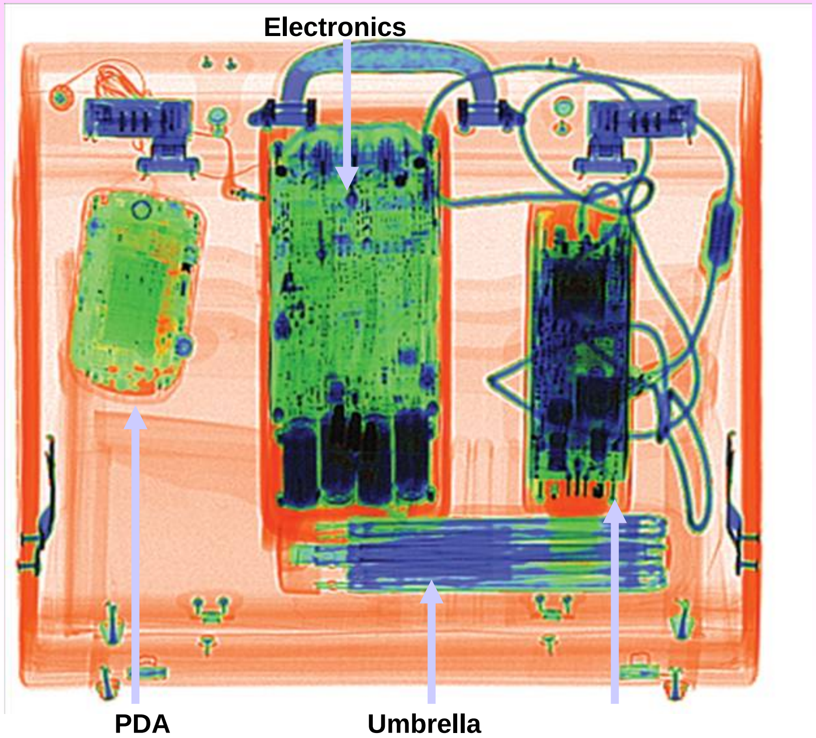
Explosives

Deodorant Stick

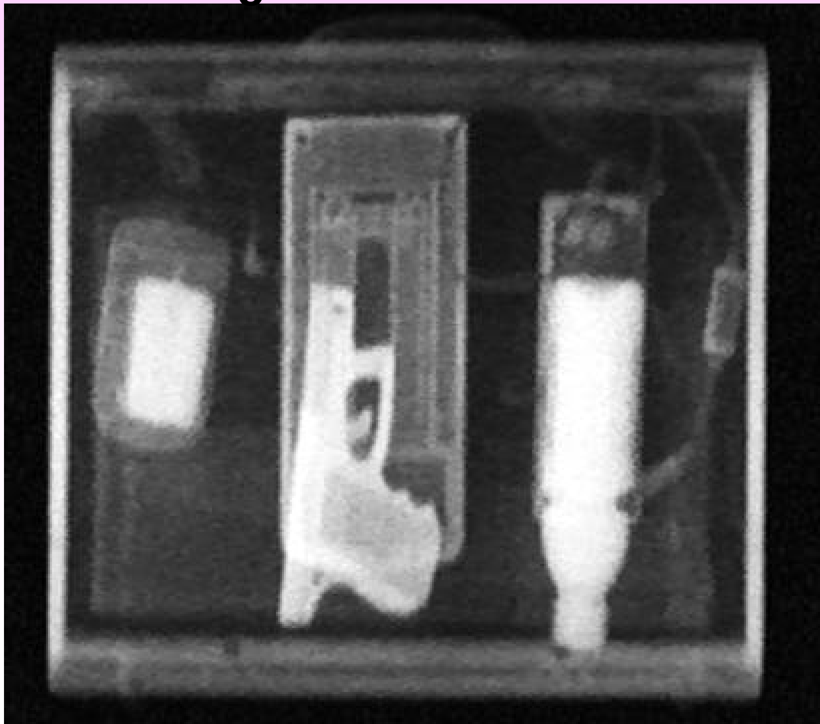


Explosives

Dual-energy transmission image



Z Backscatter has superior ability to detect organics

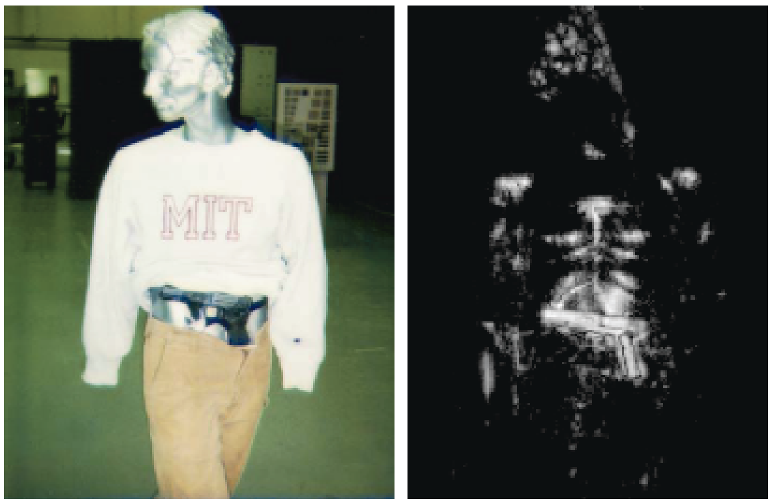


BULK TECHNIQUES: Electromagnetic

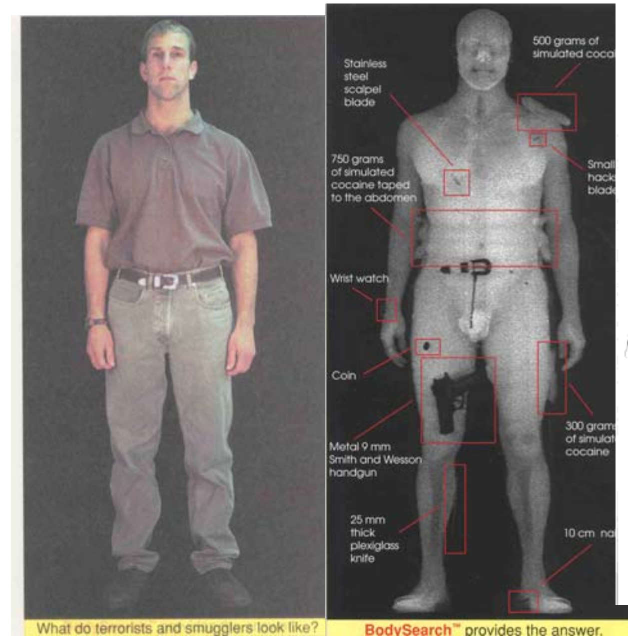
Passive Millimeter Wave,

Terahertz,

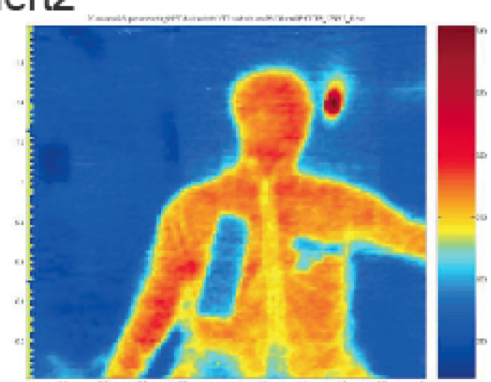
NMR, NQR, Dielectric



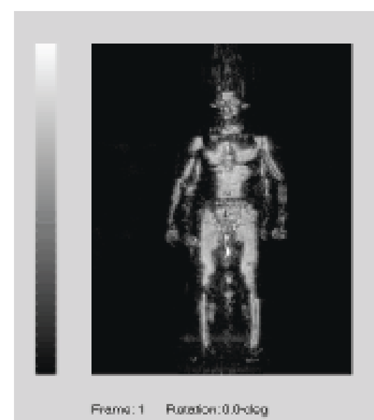
Giga-Hertz



X-ray Backscatter



Passive Tera-Hertz



Millimeter Wave

Neiderman

Other Threat Vectors & Issues

Stand-off Detection

Acquisition type	Detection sensitivity	Standoff Range (m)	Cost	Vendors	Pros	Cons
Portal Vacuum Secondary transfer material	ppb ng	1	$$	Smiths Detection GE	Fielded, most commonly used Easy to use	Need physical sample in system low chemical specificity (many interferents) Can be combined with GC for better chemical specificity, but this slows down sampling time requires radiation source requires periodic recalibration
Portal Vacuum Secondary transfer material	ppb ng	1	$$	Constellation Technology Corp Bruker Daltonics	Good chemical specificity	Need physical sample in system Cannot handle many chemicals at once Typically uses GC as a front end, slowing it down expensive
Portal Vacuum Secondary transfer material	ppb ng	1	$	Electronic Sensor Tech	No Radiation source Easy to use Sensitive to many chemicals	Sensitive to many chemicals, causing difficulty detecting explosives Gas necessary for operation Needs GC front end
Portal Vacuum Secondary transfer material	ppb ng	1	$	Scintrex Trace Thremo Electron Corporation	No Radiation source Easy to use	Need physical sample in system cannot identify specific compounds without GC, only N0x ratios Cannot identify explosives that do not have Nox
sniff	Unknown claims of ppt	1	$$	Various	can follow a signal to its source	unable to identify specific explosive Brief work time
active interrogation w/ laser	ppm ng	30	??	Applie Photonics LTD		unknown human safety Can be confused by atmospheric N and O Surface contamination can cause false negatives
active interrogation w/ laser	?	30	??	Portendo Intelligent Optical Systems		Not solar blind - Requires significantly higher laser power for daytime operation; Fluorescence of the material can hide the Raman signal
active interrogation w/ laser	?	100 to 1000 projected	$$$	Raytheon/LANL	Solar blind; Increased signal due to resonance	
Passive reception of absorbtion lines	ug/cm2	20	$ to $$	Raytheon/PSI	No active interrogation required; Several available sensors	signal affected by substrate emissivity signal affected by angle to sky

Bulk Detection for Bottle Screening

X-ray Bottle Screener

Laser Raman Bottle Screener

Microwave Dielectric Bottle Screener

Electromagnetic Wave Dielectric Bottle Screeners

Bulk Detection: Nuclear

Thermal Neutron Analysis (TNA)

$^{252}Cf \rightarrow$ thermal (slow) neutron + $^{14}N \rightarrow$ ^{15}N + γ (10.8Mev)

Fast Neutron Analysis (FNA) & Pulsed FNA (PFNA) high-energy (14 MeV) neutrons source D-T scatter off N forming characteristic γ. Nuclei-- O, C, Cl, N

Associated Particle Imaging (API)

D-T reaction $\rightarrow$ 14 MeV neutrons + 3 MeV alpha particles at 180°

Gamma Resonance Absorption (GRA) or NRA

Proton (1.75 MeV) $\rightarrow$ ^{13}C $\rightarrow$ $^{14}N \rightarrow$ γ (9.17 MeV at 80.7°)

$\gamma\ \gamma\ \gamma \rightarrow {}^{14}N \rightarrow \gamma\ \gamma$

Pulse Fast Neutron Transmission Spectroscopy (PFNTS) or PFNR

'White' fast neutrons (0.5-8 MeV), produced by D $\rightarrow$ Be. TOF is used.

Neutron Elastic Scattering (NES)

Proton $\rightarrow$ Li target $\rightarrow$ neutron (single energy, pulsed, collimated)

Neutron $\rightarrow$ C, O, N $\rightarrow$ scatter & reduce energy of neutron

PhotoNuclear Activation

γ (high-energy 13.5 MeV) + 14N $\rightarrow$ 13N

13N $T_{1/2}$ ~0 min) $\rightarrow$ positron & e annihilate $\rightarrow$ 2 photons(511 keV) 180°

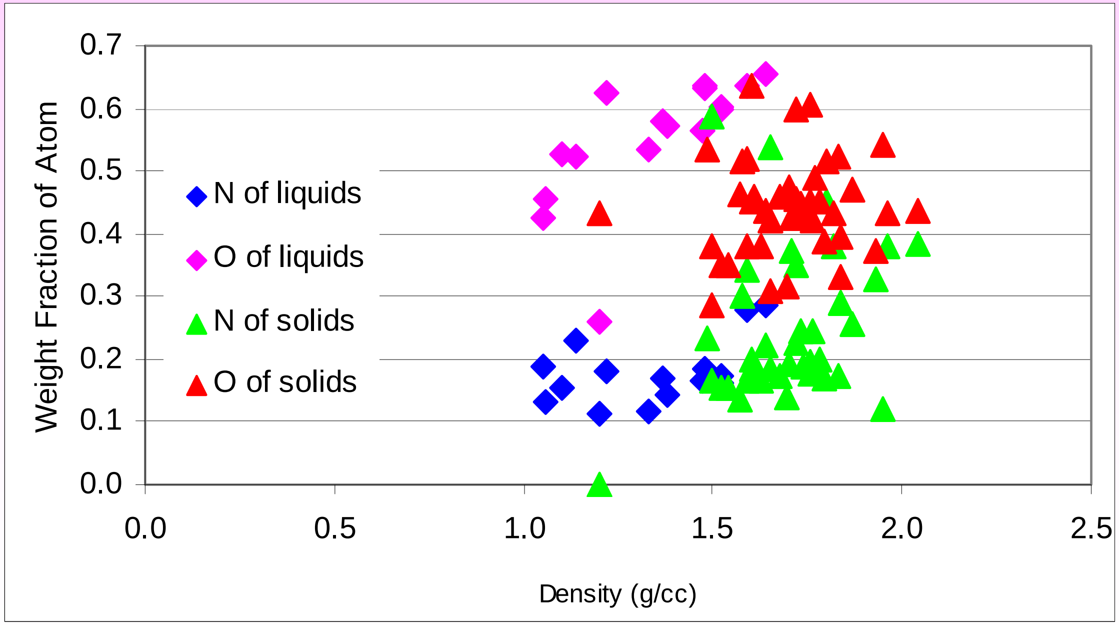
Bulk Detection: Nuclear

Nuclear techniques have penetration power & ability to discriminate chemical elements. Disadvantages include high cost, large size, shielding requirements, resolution significantly worse than x-ray.

To interrogate deeply neutral species--neutrons or high-energy photons (high voltage x-rays or gamma rays)—must be used.

Except for TNA, techniques require shielding and an accelerator.

Neutrons (5-15 MeV) or gammas (1 MeV-6 MeV) have mean free paths ~10's cm so that in cargo severe attenuation can occur.



Neutron beam is often collimated (wastes beam). Target material is required to make a mono-energetic beam.

Detectors and discrimination algorithms to compensate for cluttered background are technical challenges